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CHEMISTRY.—*Synthesis of a humus-nucleus, an important constituent of humus in soils, peats and composts.*[1] SELMAN A. WAKSMAN and K. R. N. IYER. (Communicated by C. THOM.)

The chemical nature and origin of humus in soil, in peat, in composts and in other natural substrates, where plant or animal residues are undergoing decomposition has attracted considerable attention during the last century and a half. This problem is not only of theoretical interest, but of great practical importance, since humus plays an important rôle in modifying the physical, chemical and biological properties of the soil, as well as in making the soil a favorable medium for the growth of cultivated plants.[2]

The problem of the origin and chemical nature of humus has been studied in this laboratory for more than 10 years. A number of papers have been already published, in which an attempt was made to study the process of transformation of the plant and animal residues which give origin to humus. Three general methods of approach were employed, namely:

(1) The decomposition of plant constituents of known chemical composition, such as cellulose, hemicelluloses, proteins, lignins, as well as various plant materials, such as straw, corn stalks, various leaves and needles of trees, etc., by pure and mixed cultures of microorganisms, under controlled laboratory conditions. The results obtained in these studies definitely established the fact that some of the plant constituents are decomposed very rapidly by microörganisms,

[1] Journal Series paper of the New Jersey Agricultural Experiment Station, Department of Soil Chemistry and Bacteriology. Received December 12, 1931.

[2] Summary papers dealing with the studies of the origin and chemical nature of humus were reported in Nat. Acad. Sci. **11**: 476–481. 1925; Soil Sci. **22**: 123–162. 1926; Cellulosechem. **8**: 97–103. 1927; Naturwiss. **34**: 689–696. 1927; Trans. 2nd Comm. Intern. Soc. Soil Sci. Budapest, *A*: 172–197. 1929; Amer. Jour. Sci. **19**: 32–54. 1930; Ztschr. Pfl. Düng. Bodenk. *A*, **19**: 1–31. 1931.

leaving no definite residue except the synthesized cell substance of the microörganisms, while other plant constituents are highly resistant to decomposition, especially under anaerobic conditions, and tend to accumulate, as shown by comparison with the total residual material.[3]

(2) The analysis of the organic matter or humus in the soil itself, including forest, peat and mineral soils. The results obtained substantiated markedly the findings in the first series of investigations, namely that the organic matter or humus of the soil comprises, (a) complexes of plant origin, which have resisted decomposition by microorganisms, although frequently considerably modified in their chemical nature, and (b) complexes synthesized by the microörganisms, during the process of decomposition. The first group consists largely of lignins and modified lignin complexes, and to a less extent of certain waxes and hemicelluloses, while the second group consists predominantly of proteins and certain hemicelluloses.[4]

(3) Synthetic processes, whereby complexes almost the same or quite similar to those found in the soil, peat and compost, or produced in the laboratory by decomposition of plant residues by microörganisms, have been synthesized. It is the latter phase of the investigations which will be reported here, since it completes in a way the cycle of studies and confirms the results obtained in the previous investigations by the other procedures.

Before reporting the results, however, it is necessary to define the terms commonly employed in the study of soil humus.[5] It has been recognized by the early students of the subject, such as Sprengel, Berzelius and others, that humus is not a homogeneous compound, but that it can be readily separated into two or more complexes.

[3] These studies have been described in a series of papers by Waksman, S. A. and Heukelekian, H. Jour. Biol. Chem. **66**: 323–342. 1925; Fourth Intern. Soil Sci. Conf. Rome. **3**: 216–227. 1924; Waksman, S. A. and Tenney, F. G. Soil Sci. **22**: 395–406. 1926; **24**: 275–283, 317–333. 1927; **26**: 155–171. 1928; **28**: 55–84, 315–340. 1929; Waksman, S. A. and Stevens, K. R. Soil Sci. **26**: 113–137, 239–251. 1928; Waksman, S. A. and Diehm, R. A. Soil Sci. **32**: 73–96, 97–118, 119–140. 1931; Waksman, S. A. and Gerretsen, F. C. Ecology, **12**: 33–60. 1931.

[4] These studies have been published in a series of papers by Waksman, S. A., Tenney, F. G. and Stevens, K. R. Ecology, **9**: 126–144. 1928; Waksman, S. A. and Stevens, K. R. Jour. Amer. Chem. Soc. **51**: 1189–1196. 1929; Soil Sci. **30**: 97–116. 1930; Waksman, S. A. and Reuszer, H. W. Cellulosechem. **11**: 209–220. 1930.

[5] The term *humus* is used here to designate the soil organic matter as a whole, as well as the total organic matter in composts and peat which has undergone extensive decomposition as shown by a marked change in appearance, as well as in chemical composition, from the original material.

By using an alkali as the extraction agent, it was found that a part of the humus is soluble in this reagent and a part is insoluble. The soluble part was referred to as "humic acid," "ulmic acid," "crenic acid," etc., while the insoluble part was spoken of as "humin," "ulmin," "humus-coal," etc. In more recent investigations, the alkali-soluble part is referred to as "humic matter," "humus fraction," "pure humus," and the alkali-insoluble part as "non-humic matter" or "non-humus fraction," etc.

The existence of two different groups of complexes in soil humus, one of which forms a characteristic constituent of the humus and frequently makes up the larger part of it, has been established also by such reagents as dilute H_2O_2 solution, permanganate solution, hypochlorite solution, etc. That part of the humus which was acted upon by these oxidizing agents was believed to comprise the fraction which gives to the humus its specific, characteristic properties; the accumulation of this fraction was believed to be parallel with the extent of "humification" of the plant residues. The fact that this process of "humification" is accompanied by definite chemical changes in the residual plant constituents and possibly by the synthesis of new compounds has been also brought out by the use of acetyl bromide,[6] whereby it was shown that while fresh plant material is completely dissolved by this reagent, "humified" plant material leaves a considerable part unacted upon; this fraction, or so-called "pure humus," is presumably the same or about the same as that which was previously referred to as "humic acid," "humic matter," etc.

There is no doubt that the lignin in the humus originates largely from the plant residues, with possibly certain chemical modifications, such as loss of methoxyl groups,[7] etc. The proteins, however, have been largely synthesized through the activities of microörganisms. Although in the fresh plant residues the ratio of carbon to nitrogen is from 200:1 to 50:1, the humus in the soil shows a much narrower ratio of C:N, about 10:1, with considerable variation, depending on the nature of the organic residues, extent of decomposition, environmental conditions, etc. This great relative increase in nitrogen content can be explained only by the fact that the nitrogenous complexes in the humus are rendered resistant to further rapid decomposi-

[6] Karrer and Bodding-Wieger. Helv. Chem. Acta, **6**: 817. 1923; Springer, U. Ztschr. Pfl. Düng. Bodenk. *A*, **11**: 313-359. 1928; **22**: 135-152. 1931; Grosskopf, W. Suddeut. Forst. Jagdz. 1931, p. 33-48.

[7] See Fuchs, W. Die Chemie der Kohle. J. Springer, Berlin. 1931.

tion. This is of considerable practical importance, since it indicates that either the organic nitrogenous complexes in the humus are not of a protein nature or, which is probably more correct, that they are not in a free state, otherwise they would decompose as readily as the plant and animal proteins ordinarily do.

A detailed study of the chemical composition of the organic matter in forest soils and in inorganic soils brought out definitely the fact that humus, or the organic matter of the soil which has undergone considerable decomposition, consists largely of two chemical complexes, namely lignin (40–45 per cent of the total humus) and of protein (30–35 per cent of the total humus), with smaller quantities of other substances, especially hemicelluloses, and to a less extent fats, waxes and others. In spite of the high protein content of the humus, the nitrogen is not available to the growth of higher plants. The possibility that we are dealing here with the formation of a tannin-protein or a lignin-protein complex[8] which would render the protein resistant to microbial attack has been suggested. It has also been suggested[9] that the formation of the resistant "humus" complexes of the soil is due to the chemical interaction of carbohydrates with proteins.

Among the other characteristic properties of humus, to which attention may be called here, is its high base-combining power, which gives it a strong base exchange capacity, a phenomenon very important in soil processes; this property of humus exists only to a limited extent in the original plant material, and is considerably greater than that of lignin.

Since lignin and protein were found to make up a large percentage of the total constituents of humus, and since these substances were found to give to humus its most characteristic properties, it was considered important to begin the synthesis of humus with these two complexes. By mixing lignin and protein in the same proportion that they exist in the soil organic matter, and allowing the mixture to undergo decomposition by microörganisms in sand and solution media, it was found that lignin had a depressive effect upon the decomposition of the protein, as measured by the evolution of CO_2 and the formation of ammonia. However, this depression was only

[8] Dehérain, P. P. Ann. Agron. 14: 97–133. 1888; Hobson, R. P. Thesis, Univ. London, 1925; Moeller, W. Der Gerber. No. 1000, 1003, 1008. 1916. (Chem. Centrbl. II, 856. 1916; I, 30, 440. 1917); Jensen, H. L. Jour. Agr. Sci. 21: 38–80. 1931.

[9] Maillard, L. C. Genèse des matières protéiques et des matières humiques. Paris, 1913.

quantitative in nature, amounting to between twenty-five and fifty per cent of the total decomposition; in other words, in the presence of the lignin mixed mechanically with the protein, there was twenty-five to fifty per cent reduction in the amount of protein decomposed in a given period of time.

The protein was next dissolved in an alkali solution, and mixed with three to five volumes of a similar solution of lignin; the reaction of the mixture of the two solutions was then adjusted to a pH of about 4.5, where a precipitate was formed. The precipitate was now washed, dried and allowed to decompose. The complex underwent only a very limited decomposition, not much more than the "humic acid" obtained from soil or peat, by extraction with alkali and precipitation by acid.

By introducing into the precipitating mixture bases, especially calcium, magnesium, iron, all of which are important in soil processes, and allowing precipitation to take place at a pH of about 7.0, a complex was obtained which showed all the characteristic properties of the important constituents of soil humus, formerly referred to as "humic acid." Both in appearance, and in their chemical, physico-chemical and biological properties, the preparations were similar to the various "humic acid" or "α-humus" preparations that can be obtained from different soils.

The lignin used for this purpose was prepared by extracting straw, previously treated with water and hot dilute mineral acid, with 4 per cent NaOH solution under 15 pounds pressure; the lignin was precipitated with hydrochloric acid, and washed free from chlorides; the lignin thus prepared contained only traces of ash, nitrogen and carbohydrates. As a source of protein, casein prepared after Hammersten and gliadin were employed. Five parts of lignin and one part of casein were separately dissolved in hot alkali solutions, the solutions were well mixed and the reaction adjusted by hydrochloric acid to pH 7.0; on adding an excess of $CaCl_2$ solution, the complex was precipitated; it was then washed free from chlorides. In a similar manner magnesium and iron compounds of the ligno-proteinates were prepared. The chemical composition of the "synthesized humus" thus prepared in the laboratory and the "natural humus" or the "humic acid" isolated from the soil are nearly the same and their behavior to different chemical reagents is alike.

The decomposition of these ligno-proteinates was tested in solution and in sand media, inoculated with pure and mixed cultures of soil

microörganisms. Their decomposition was no more rapid than that of an equivalent amount of soil humus, prepared from peat or from soil (so-called "humic acid" or "α-fraction of humus").

These "synthesized humus" complexes were found to have a highly beneficial effect upon soil microbiological processes, as shown by their influence upon the decomposition of dextrose by soil bacteria, growth and fixation of nitrogen by Azotobacter (especially the iron complex), decomposition of cellulose by bacteria and fungi, etc. However, although containing about 2 per cent of nitrogen, the complexes cannot be used as sources of nitrogen by the various soil organisms. The proteins have become "lignified" and in this condition cannot be readily attacked by the common soil microörganisms.

Chemically and in their base-exchange capacity the "artificial-humus" complexes behave exactly in the same manner as that part of the soil humus which is soluble in alkalies and is precipitated from the alkali solution by acid, namely the "humic acids" or the "α-humus."

The authors believe that they have succeeded in synthesizing from plant constituents, in the laboratory, by simple chemical treatment, a complex which has the characteristic properties of the most important constituent of the soil humus. The most appropriate name for this complex would have been "synthetic humus," which it actually is; however, since this term has been so much used and misused historically for preparations which have nothing to do with the soil humus, such as the dark-colored material obtained on treating various sugars and other carbohydrates with sulfuric and hydrochloric acids, this term will be avoided. It is proposed to apply to these complexes the name *humus-nucleus*, since they form the nucleus of the humus in soils, peats and composts, making up 50 to 80 per cent of these materials, depending on their nature and degree of decomposition.

The mechanism of formation of the *humus-nucleus* in soil can be schematically presented as follows:

When plant residues are introduced into the soil, rapid decomposition will set in, under favorable conditions of temperature and moisture, immediately. However, the plant material does not decompose as a whole; some of the constituents, especially the water-soluble substances, such as the sugars and amino acids, are attacked immediately by a large number of fungi and bacteria; these are followed soon by the decomposition of the starches, proteins, certain hemicelluloses (pentosans, mannans) and the true cellulose; some of the

constituents, like the sugars, starches and proteins are attacked by a great variety of organisms, while others, like the cellulose, are decomposed only by certain specific fungi and bacteria, some of which are highly selective in nature; the lignin is, of the more abundant plant constituents, most resistant to decomposition, especially under anaerobic conditions. These decomposition processes are accompanied by continuous synthesis of microbial cell substance, due to the rapid multiplication of the bacteria and fungi decomposing the plant constituents, to the rapid development of the protozoa, nematodes and other invertebrates feeding upon the bacteria and the fungi as well as upon some of the undigested or partly digested plant residues, and finally to the development of various microörganisms feeding upon the products of the metabolism of the other organisms, such as the algae, autotrophic bacteria, etc. These synthetic processes result in the building up of considerable quantities of microbial cell substance which is rich in proteins (10 to 60 per cent) and in certain hemicelluloses (microbial gums, slimes). In view of the fact that this cell substance is considerably richer in nitrogen than the original plant residues (most of the plant residues containing only 1.2 to 6 per cent protein), there is a continuous accumulation of the protein with the advance of the decomposition of the plant residues. This protein does not remain in a free state or in the microbial cell substance, but with the breakdown of the latter by other microörganisms, the protein combines with the lignins and the modified lignins of the plant residues, liberated as a result of the decomposition of the cellulose, to give rise to ligno-protein complexes; this renders the proteins resistant to rapid decomposition. These complexes are acid in nature, and in the absence of bases in the soil or in the plant residues, they make the humus acid, as in the case of the upper layers of organic matter in the raw-humus forest soils. However, in the presence of bases, especially calcium and magnesium, they interact with these to give rise to calcium and magnesium ligno-proteinates, which are neutral in reaction or only slightly acid. With an increase in the formation of the ligno-proteinates, especially their basic compounds (Ca, Mg, Fe, etc.), there is a darkening in the color of the mass undergoing decomposition; this dark color is a characteristic property of the ligno-proteinates, depending on the degree of their oxidation, nature of bases, etc.

The ligno-proteinates form the most essential constituents of the soil humus or the *nucleus of the humus*. They are accompanied by various other organic complexes, of plant, animal and microbial

origin, undecomposed or in the process of decomposition. Here belong certain hemicelluloses, especially pectins and other uronic acid complexes, a small amount of cellulose (especially in the surface layers of forest soil), fats, waxes, corky substances, various organic acids, alcohols in a free or combined state, etc.

The total organic matter of the soil, or the soil humus, can thus be divided into two distinct groups:

1. The *humus-nucleus* consisting of ligno-proteinates, combined with bases, thus giving H-ligno-proteinate, Ca-ligno-proteinate, Fe-ligno-proteinate, Al-ligno-proteinate, and probably also with silicates and phosphates, to form organic-inorganic complexes, which give to the soil its characteristic colloidal properties. These ligno-proteinates are probably combined also with certain other organic complexes, such as the hemicelluloses. This is the fraction which has formerly been referred to as "humus," "humic acid," "ulmic acid," "humic bodies," etc. It is the mobile fraction of the soil organic matter (which is probably active in removing the bases of the surface soil layer in the process of podsolization). It is the resistant fraction, which immobilizes the soil nitrogen. It is the "humified" fraction, which gives to the soil its characteristic color and organic colloidal properties.

2. The remaining constituents of the humus, comprising cellulose, hemicelluloses, starches, fats, waxes, etc. This fraction consists largely of plant residues in the active stages of decomposition and is particularly abundant in composts, in the surface layers of forest soils, in highmoor peats, etc., while it is low in those natural substrates where the plant organic matter has undergone considerable decomposition, such as inorganic soils, lowmoor and sedimentary peats, and may even disappear in the course of time, as is possibly the case of Cassel Brown and coal. This fraction has been usually referred to as "humin" (although under this term as well certain of the ligno-protein complexes might have been included), "non-humic bodies," etc., as well as "crenic," "apocrenic," "fulvic," "humal" and other so-called acids.

In view of the fact that the ligno-proteinates, or the *humus-nucleus*, tend to have a definite ratio between the lignin and the protein, we would also expect a more or less definite ratio between the carbon and nitrogen in the complex; actually the preparations synthesized and isolated from the soil contain about 3 per cent nitrogen, which gives about 81 per cent lignin and 19 per cent protein. By allowing 62 per cent for the carbon content of the lignin and 50 per cent for the

carbon content of the protein, and four parts of lignin to one part of protein the complex should contain theoretically 59.6 per cent carbon. However, the presence in the soil humus of other organic complexes, of a lower carbon content, will reduce this percentage of the carbon in the humus, especially in the case of the surface layers of forest soils, composts, highmoor peats, which contain considerable quantities of cellulose, hemicelluloses and other complexes, of a lower carbon content. These ligno-protein complexes are not absolutely resistant to decomposition, but can be attacked by certain organisms, such as the edible mushroom and probably various other higher fungi, such as the tree-forming mycorrhiza. The correlation between the two groups of complexes in the humus need not, therefore, hold true for all forms of humus. One can readily imagine that under certain conditions, as in certain processes of podsolization, some of the compounds, such as the proteins (possibly due to the destruction of the lignins by certain specific fungi), should be removed more readily than the others, as a result of which we may find in the accumulation horizon organic complexes of a higher nitrogen content. Under other conditions, as in highmoor peats, where the accumulation of nitrogen complexes is only very limited, the humus-nucleus may be much less abundant than the remaining part of the humus; this nucleus, if formed at all may be poorer in protein than the nucleus in soil or lowmoor peats.

While lignin itself has only a very low base-exchange capacity (about 6.5 M. E. per 100 gm.), the ligno-protein complexes were found to possess a very high capacity for base absorption and exchange (between 120 and 130 M. E.). Lignin no doubt undergoes, in the process of decomposition of plant residues, certain processes of oxidation and de-methoxylation. In this state, it interacts with the proteins, largely synthesized through the activities of the microorganisms. The nature of the complex formation is still problematical. Several possibilities present themselves. One is between the NH_2 groups of the protein molecule, reacting with a carbonyl group, either ketonic or aldehydic, in the lignin molecule, as shown by the following reaction:[10]

$$\underset{\textit{Lignin}}{C_{52}H_{46}O_{10}(OCH_3)\cdot(COOH)\cdot(OH)_4\cdot CO} + \underset{\textit{Protein}}{H_2N\cdot R\cdot COOH} \rightarrow$$

$$\underset{\textit{Humus-nucleus}}{C_{52}H_{46}O_{10}(OCH_3)\cdot(COOH)\cdot(OH)_4\cdot C=HN\cdot R\cdot COOH} + H_2O$$

[10] This reaction has been suggested by Dr. M. Phillips of the Bureau of Chemistry and Soils.

A compound of this type would be quite stable, especially to hydrolytic agents. It also explains the high base exchange capacity of the ligno-protein complexes. The protein is an amphoteric substance and, when the NH_2 group is tied up by combining with a carbonyl group of the lignin molecule, the acidic character of the COOH groups becomes prominent, which results in a decided increase in the base-exchange capacity of the complex. The COOH groups of the lignin molecule may also become more reactive with bases, as a result of the complex formation. The possibility of interaction of the NH_2 groups with the phenolic OH groups of the lignin or the acidic COOH groups may also be suggested, although the complexes of this type would be less stable than is the case of the "humus-nucleus."

The synthesis of artificial humus, or a lignin-protein complex, offers numerous possibilities for further study, which would lead to the elucidation of the chemical nature of soil humus and its rôle in soil processes. Some possibilities may be briefly outlined as follows: 1. The nature of the replaceable hydrogen, since, aside from the fact that the original lignin has a low base-exchange capacity, the complex formed seems to possess a higher capacity than can be accounted for by the COOH group of the protein molecule. 2. The possibility of combining varying numbers of protein molecules with a given number of lignin molecules, thus accounting for the varying nitrogen content of the soil humus, formed in different soils, at different depths and under different climatic conditions. 3. The possibility of certain bases, like the sesquioxides, of forming compounds possessing definite amphoteric properties. 4. The possibility of using this complex for attaching molecules of other compounds, especially the hemicelluloses, which, due to the uronic acid complexes, possess base-combining properties. 5. The possibility of building up organic-inorganic complexes, which may account for a number of soil reactions, such as availability of certain soil minerals, especially iron, phosphorus and potassium, for plant nutrition, etc.

PHYSICAL GEOGRAPHY.—*The classification of peat soils.*[1] A. P. DACHNOWSKI-STOKES, U. S. Bureau of Chemistry and Soils.

I

It need scarcely be pointed out that classifications are subjective concepts. They are more or less adequate means by which objects under investigation, whether peat soils or other materials, are arranged in an orderly fashion.

[1] Received December 7, 1931.

Classification has three purposes which though distinct, can not well be dissociated. It may be employed (1) to facilitate identification and differentiation of the objects classified, (2) to show relationships and to organize our knowledge concerning the particular objects, and (3) to serve various practical interests, such as agriculture and industry. Thus it happens that on seeking a definition and classification of peat soils great difficulty is encountered in finding a nomenclature or system that avoids including more than was intended, or leaving out something which should be taken in.

In the popular mind peat soils are still classed as peat and muck. The differences are based either on a simple character or on very simple combinations of characters. Arrangement according to any readily perceived, simple property is comparatively easy and is the first to suggest itself.

The first classifications of peat soils made by scientists were based on color, weight, ash content, reaction, and other properties which are still depended on as means of identification. Those likenesses among peat and muck materials which are due to their possession in common of some color, weight, or calorific value were believed to coexist with other properties and hence peat soils were placed together which later proved to be unlike in their essential natures.

In recent years it has become obvious that the arrangement of peat and muck according to combinations of properties, which though fundamental are not conspicuous, requires analyses based on considerable field investigation and laboratory work. The grouping of complex objects such as peat soils can reach its complete form only by slow steps and after analysis has made more progress. As the pedographic knowledge of regional peat areas increases it becomes possible to ascertain which properties of peat soils are most characteristic, and to make groups of the members that have many properties in common. The ultimate arrangement will serve not only to identify peat soils completely and express the greatest information regarding their character in any of the major groups but it will also permit the prediction of a great number of facts about deposits of peat in other countries and by so doing reveal the precise correspondence between "our concepts and the reality."

II

The writer's own investigations illustrate well the phases through which classification of peat soils is passing. In early attempts at some systematic manner, all kinds of peat were separated by conspicuous

physical characteristics into three classes comprising woody, fibrous, and sedimentary peats. The limits were narrower and different otherwise from those assigned to them by earlier observers. In successively later attempts more regard was paid to botanic composition coordinated with the simplest analytical methods such as those employed for crops and feeding stuffs, for determining a number of chemical complexes which represent essential but generally inconspicuous changes in the transformation of organic materials.

Passing through various modifications in which the arrangement was dictated by the viewpoint of degree of decomposition and the recognition of conspicuous morphological features in the inherent structure of peat deposits, another order of facts came to be recognized,—those of development.

Ecological studies led to an arrangement of peat deposits into groups and subgroups in such a way as to display the developmental differences produced by climate, by natural vegetation, and by the larger topographic diversities existing among the several great groups of peat areas in this country. The fundamental differences in the development of peat deposits—that is, in origin, sequence of parent peat layers, and the varying stages of profile development—did not admit of being placed in a linear order, but only in an arrangement perhaps not unlike that regarded as a branching of clusters. If it be supposed that dots representing type profiles form clusters expressing genera and species, the names of which it is impracticable to insert here, and if the successively larger groups and their general distribution constitute orders in the subkingdom of organic soils, an approximate idea will be formed of some of the facts that should be included in a classification of peat soils. The relationships of these diverging groups cannot, however, be expressed on a flat surface, or in space of three dimensions, but must also include the more significant contrasts ascribed to time. Though under present conditions it seems too soon to attempt a definite scheme of classifying peat soils and their relationships, yet it has seemed that an outline of a tentative scheme may be ventured presenting in a general way such relationships as they are now conceived. In a forthcoming publication a scheme will be described dealing with American peat deposits, their characteristic profiles and classification. In this classification is exhibited a conclusion of basic significance, namely that the structural profile features by which members of one group differ from those of another, have developed under dominating influences active in past periods; they are largely

products of forces and changes in environmental conditions that operated long before the present period. In the present paper an illustration will be given to indicate the nature of the conditions which caused such differences in former times, and the character of the peat soils that developed in various layers of the profile under the influence of the major soil-making processes.

III

Facts which illustrate the development of peat areas and their soils, and the influence of surrounding conditions, are abundant and familiar to many. The restriction of different kinds of vegetation to their particular environment is the broadest, basic fact of ecology and of geographic distribution. There are extensive plant communities that are respectively aquatic or amphibious, and others that are confined to the land. Besides hydrographic and topographic limitations there are the familiar limitations made by climate. These factors vary from place to place and from time to time, producing by their effects an extension or restriction on vegetation and on soil formation.

To the limiting environmental factors must be added others imposed by the reciprocal relations of plant associations, either competing, directly destructive to one another, or coacting in what is now known as succession and the development of the climax community. Plant associations are held together in a web of relations, and any considerable modification which one aggregation of plants undergoes acts indirectly on others, eventually changing the conditions of nearly all other communities associated with them. In the development of peat deposits from extreme conditions in the water relation, whether building up a substratum from a lake bottom or from land or bare rock, the plant communities involved and their habitat change more or less rapidly. Each community of plants contributes certain effects to this developmental process; each modifies its own environment in the quantity of light and heat, the movement of air, water, and salts, the activity of soil microörganisms, and hence its own chances of permanency. Thus takes place a succession in which differently constituted plant communities replace one another, each forming a layer of peat with characteristic soil properties, each contributing modifications to the development of an organic aggregate, until the conditions of drainage, aeration, and the activity of microörganisms become stable enough to produce a relatively permanent or climax stage of peat soil

and vegetation cover. It is logical to assume that each climax vegetation should be and probably is a center of organic soil production, characteristic of that particular region and its vegetation.

Peat areas of the type of profile development representing the uniserial succession from lakes and ponds have been described in many publications. They may be found as minor or intermediate successional stages in adjoining regions and some of the earlier stages may have a wide distribution in regions characterized by a different vegetation climax. But the accumulation of evidence has brought the conviction that many peat profiles are made up of layers marked off from one another by great morphological contrasts, and that the strongest divergences in structural characteristics are products of changes in climate and plant migration.

The progress of peat investigations has shown with increasing force the extent to which past environmental changes have contributed to the development and distribution of characteristic peat soils as expressed in the profile during the course of its formation in space and time. It was shown elsewhere that departures from the general, uni-serial development of peat deposits may include abnormal and to a greater or less extent complex profiles. In fact, development may have taken place repeatedly in the same direction, and in no connection with the present environmental conditions. A classification of peat soils so comprehensive as to stimulate investigation into every feature of peat deposits should, therefore, include information not only regarding changes that occur now or may occur in the near future, but also the characteristic materials that have been produced in the distant past. It should include data on the nature of the processes recorded in the history of the profile, and bring out the contrasts and important properties of the respective products that developed from the parent material at earlier times.

IV

In all peat deposits, layers of buried plant remains are found in greater or less abundance which were exposed in varying degrees to the influence of soil-making processes and to partial or extensive decomposition. The differences between layers of peat are, speaking generally, small and continuous where the main environmental condition, notably the quantity and quality of the ground water, was a continuous factor. Leaving out of consideration those paralellisms among trends of development which characterize type profiles belong-

ing to each group or subgroup, the occurrence of morphological differences is greater where the factors of a major process that caused such differences were more dynamic and effective. It will necessarily happen that changes in local conditions to which a type has been subjected directly or indirectly will give no evidence of modifications that have generic value; the transitions will be less numerous in peat areas which in the past were less variously conditioned. The type profile may be defined, therefore, as a unit the boundaries of which include transitions and variations in color, thickness, or reaction, but not in the number, sequence, and character of the layers. The latter express the direction as well as the stage of profile development, and they show the extent and the kinds of effects produced by the changes in environmental forces which influenced decomposition. The contrasts in parent materials, degree of decomposition, and the character of the resulting peat soils will be comparatively large and abrupt where the changes in environment were correspondingly wide or sudden or where modifications of the parent material took place more or less completely as a result of long-continued soil-forming processes.

Instructive examples of profiles showing remarkable changes in the course of their development are furnished by deposits of peat in northern Minnesota, Wisconsin, and Michigan. The type profile described below is located near Three Lakes, Oneida County, Wisconsin. The following brief summary of its morphological features and history of development is intended to show the problems which a classification of peat soils must solve, and to explain structural characteristics that are otherwise unaccountable.

V

In Menominee County, Michigan, in Oneida, Bayfield, and Douglas Counties, Wisconsin, and in St. Louis, Lake of the Woods, and Roseau Counties, Minnesota, are areas whose profile consists of five separate layers. In the order of sequence, from below upward, they are composed of reed-sedge peat, followed by woody peat, and a surface layer of sphagnum-moss peat. Of chief interest is the presence of a second and well defined younger layer of woody peat which separates the surface layer of moss peat into two distinct parts.

The basal layer of reed and sedge peat is generally yellowish brown in color, poorly decomposed and coarsely fibrous to felty matted, indicating that the deposit developed from a marsh stage of vegetation under conditions of water level at or near the surface. The flat-

pressed rhizomes represent largely the well preserved cuticular tissues of reeds and a variety of sedges. The thickness of the layer and the lack of marked differences in respect to degree of decomposition and color show that the layer was not impoverished and not exposed to contrasts in weathering, leaching, or evaporation and the concentration of salts. At that time reed marshes were spreading over wide sections of this country. They continued to persist as dominant communities for a long period, and hence a deposit was formed consisting essentially of reed-sedge peat to a height approximating that to which ground waters rose in the capillary spaces. Differences in the character of the peat soils which may have developed from the parent material of this extensive unit of natural vegetation are much obscured by the varying botanical composition of the whole layer.

At a later period various portions of the ancient marshes in the Great Lakes region became wooded with thickets of deciduous shrubs, finally culminating in a swamp forest of mixed conifers and hardwoods. Cedar and tamarack were prominent with a small percentage of deciduous trees, both as a mosaic of pure stands and a general mixture which included an undergrowth of herbaceous plants. The properties of that portion of the parent reed peat in contact with the woody material were almost entirely changed; reed muck of varying depth merged with the dark-brown, partly granular woody material and ligneous fragments derived from the swamp forest.

With such evidence the assumption is not altogether unwarranted that the reed muck in contact with the wood peat soil reflects a fluctuating, lowered water level, better drainage and aeration. The penetration of woody roots into the reed peat, the shading of the organic material by a forest crown, and the accumulation of granular residue, stumps of trees, fallen timber, branches, bits of fungal mycelium, and the litter of needles, scales, and cones indicate the diversity of growth forms of this stage of vegetation. They reveal differences in physical conditions and disclose the presence of aerobic microörganisms and wood-destroying fungi causing decay.

How long ago the miscellaneous plant remains of the ancient forest were exposed to an environment so radically different in soil-forming conditions can not be determined precisely. Doubtless the process was gradual and continuous, removing effectively the more soluble organic complexes and developing the woody residue; but there may have been times when the disintegration of ligneous tissues was more rapid than at others.

One more striking fact must here be set down. It is noteworthy that trees of pine, tamarack, cedar, and several deciduous species of large diameter occupied at one time a section of the Great Lakes region in which today only dwarfed spruce dominate. It is well known to ecologists that a stage of mixed conifer and hardwood forest was more extensive several thousand years ago than today. Its geographical position is recorded by plant remains found well within the limits of the boreal region and in peat deposits of southeastern Canada. They suggest a period marked by a warm and generally dry climate and by the movement northward of deciduous forests.

As pointed out above, the layer superimposed upon the woody peat soil is yellowish-brown, spongy-fibrous, poorly decomposed moss peat, grading to reddish-brown partly decomposed material derived from several species of Sphagnum. The penetration of woody underground stems from shrubby heaths is chiefly along shallow depths extending from 4 to 7 inches below the surface. Stumps of small spruce trees are also found at this level. With the exception of the dome-shaped deposits along the northeastern coast of Maine and the slightly curved areas near Corona and Floodwood, Minnesota, the surface layer of moss peat in the Great Lakes region is rarely three feet in thickness. The evidence so far secured strongly suggests that this region may have experienced the effects of a marked shifting of ice movement in northern Canada, and that a great change in temperature and humidity affected the northern portion of the Great Lakes Basin. The southward swing of colder conditions was accompanied by a southward movement of Sphagnum mosses, followed by an arctic floral element, by heaths and spruce. That such disturbances affected also human migrations is a fact to be found recorded in history. The dependence of Sphagnum mosses upon cool and moist atmospheric conditions, their habit of growth, and the capacity of moss peat for taking up and holding large quantities of precipitation water, give these plant remains a unique quality toward checking aeration, bacterial activity and decomposition, and intensifying an acid reaction. The rôle of Sphagnum mosses in the invasion of reed and sedge marshes and in the ultimate extinction and burying of forests has been described frequently. As a plant community Sphagnum mosses and their associates had no relation, either floristic or successional, to the swamp forest of that earlier period. Even today they stand in great contrast as outposts to the south, outside the limit of their present climax in the boreal region. The layer of moss peat points, therefore, to a

change to colder and more humid conditions, to leaching, the loss of nutrients, and the general impoverishment of soils and vegetation.

It may be well to note briefly that the second and younger layer of woody peat soil represents a mixed coniferous forest of possibly parallel nature to the "Grenzhorizont" of European highmoors. The occurrence of dark-colored woody material in an advanced degree of decomposition between layers of comparatively well preserved moss peat is a striking morphological fact not explicable as a result of the forces that led to the accumulation of moss peat. It points to a shift of climatic conditions and to a readvance of mixed conifer forests and deciduous trees from the south and east. It involves a process of decomposition whereby woody plant remains were converted into residual products that were left in place. It reflects environmental conditions which were temporarily much less cold and humid as judged by the vegetation that formed the intervening, impoverished layers of moss peat.

There is little to be said concerning the trend of peat soil formation in the Great Lakes today. It represents an approach toward conditions which displace and exclude Sphagnum mosses and their associates, but favor the dominance of a vegetation cover which finds its extreme expression in a mixed conifer swamp forest. These facts are evidence pointing toward an oncoming period of desiccation and a renewed tendency to the development of forest soil. It is not unreasonable, therefore, to regard the modern trend in the climate of North America as characterized by irregular fluctuations, and as passing once more to a warmer and generally drier climate than was that of a few thousand years ago.

Thus one is brought to realize that the development of peat profiles is an orderly thing. Especially will this be the case where profiles of individual deposits have become relatively definite and where shifts in environmental conditions were accompanied by a corresponding complexity in structural features. The resulting differences in the character of peat soils may in such cases become so pronounced as to greatly obscure the relation to the parent material.

With due allowance for the difficulties encountered in reconstructing past environmental conditions, it is now generally recognized that peat investigations are the best approach to a knowledge of the nature of past changes in environment. This implies that they tend likewise to show the effects of the major environmental processes in developing peat soils of widely differing character. Doubtless an exhaustive study of profiles would disclose that the soil-making processes of former

periods bear to our present contrasting conditions a corresponding relationship.

But how past climatic and other dominating factors have worked in the production of peat soils cannot be thus accounted for. This is to be determined mainly by more detailed investigations of peat profiles and the chemical constituents of peat soils coördinated with more adequate knowledge concerning the microörganisms capable of bringing about decomposition.

BOTANY.—*Five new species of* Bomarea *from Peru.*[1] ELLSWORTH P. KILLIP, U. S. National Museum.

In the course of recent studies which I have been making of Peruvian material of the amaryllidaceous genus *Bomarea*, five new species were found to be represented. Descriptions of these follow:

Bomarea caudata Killip, sp. nov.

Caulis volubilis glaberrimus; folia oblongo-lanceolata, abrupte acuminata basi rotundata membranacea supra glabra subtus in nervis primariis pilis crispatis hyalinis sparse hirsuta; bracteae lanceolatae et setaceae; umbella ca. 18-radiata dense rufo-tomentosa; ovarium turbinatum dense rufo-tomentosum; sepala oblanceolata longe corniculata coccinea; petala sepala subaequantia spathulata in costa rufo-tomentella viridia, brunneo-maculata.

Vine; stem subangulate, glabrous; petioles up to 8 mm. long, strongly corrugate at margin; leaves oblong-lanceolate, 7 to 10 cm. long, 2.5 to 3.5 cm. wide, abruptly acuminate at apex, rounded at base, membranous, glabrous above, sparingly hirsute with long crispate hyaline hairs on the principal nerves beneath, the nerves about 1 mm. apart, unequally prominent; bracts of two forms, the outer lanceolate, 1.5 cm. long, 6 mm. wide, the inner setaceous, 1 cm. long; umbel about 18-rayed, the rays 2.5 to 3 cm. long, straight, densely rufo-tomentose, ebracteolate; ovary turbinate, densely rufo-tomentose; sepals oblanceolate, about 2 cm. long, 7 to 8 mm. wide, dorsally corniculate near apex (horn 5 to 6 mm. long), sparingly rufo-pilosulous or glabrous, blood-red; petals spatulate, subequal to sepals, barely 1.5 mm. wide in lower half, 5 to 6 mm. wide toward apex, rufo-tomentellous on midrib dorsally, otherwise glabrous, green, brown-spotted; stamens 2 to 2.5 cm. long, the anthers ovate, 3.5 mm. long, 2 mm. wide.

Type in the herbarium of the Field Museum of Natural History, no. 562,472, collected in evergreen forest, Choimacota Valley, Province of Huanta, Department of Ayacucho, Peru, altitude 2,800 to 2,900 meters, February 28 to March 10, 1926, by A. Weberbauer (no. 7559).

The only other species of *Eubomarea* with long-horned sepals are quite different. *Bomarea cornigera* is glabrous throughout and has leaves not over 1.5 cm. wide and an umbel of only 1 to 4 flowers. *Bomarea cornuta* has

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forked umbel rays, and is closely related to *B. ovata*. The proposed species is probably allied to *B. purpurea*, from which it differs in the horned, proportionately broader sepals and a scantier indument on the under surface of the leaves.

Bomarea nematocaulon Killip, sp. nov.

Caulis tenuis subteres glaber ad apicem glanduloso-puberulus foliosus; folia anguste oblonga vel lanceolato-oblonga, apice acuta et crassa, brevipetiolata parum revoluta 9-15-nervia supra glabra subtus in nervis pilis crispatis hyalinis strigillosa; bracteae 3–4 foliis similes; umbellae 2-3-radiatae, radiis glanduloso-puberulis 1-2-furcatis, bracteolis lineari-lanceolatis acuminatis revolutis; perianthium parvum, segmentis aequalibus; ovarium subglobosum truncatum glanduloso-puberulum; sepala oblanceolata saepe mucronulata extus ad basin glanduloso-pubescentia luteo-rubra; petala unguiculata lutea ad apicem purpureo-maculata.

Vine; stem slender, wiry, subterete, glabrous, glandular-puberulent at tip, leafy (internodes 1.5 to 3 cm. long); leaves narrowly oblong or lanceolate-oblong, 1.5 to 3.5 cm. long, 0.4 to 1 cm. wide, subacute and callous-thickened at apex, rounded or rarely acutish at base, petiolate (petioles 2 to 5 mm. long), slightly revolute, 9 to 15-nerved (nerves uniform, elevated on upper surface, the cross-veins prominent), coriaceous, dark green, glabrous and sublustrous above, paler beneath, strigillose with crispate hyaline hairs on the nerves beneath; bracts 3 or 4, similar to the leaves; umbel compound, 2 or 3-rayed, the rays up to 4 cm. long, glandular-puberulent, once or twice forked, bracteolate at the forks, the bracteoles linear-lanceolate, 5 to 8 mm. long, up to 2 mm. wide, acuminate, revolute; flowers 1 to 1.5 cm. long, the sepals and petals equal; ovary subglobose, truncate, glandular-puberulent; sepals oblanceolate, often mucronulate, proximally glandular-pubescent without, otherwise glabrous, yellow-red; petals unguiculate, the claw and blade nearly equal in length, yellow, blotched distally with purple; stamens 5 to 7 mm. long, included, the anthers ovate-oblong, about 2 mm. long.

Type in the Field Museum of Natural History, no. 535,916, collected at Playapampa, Department of Huánuco, Peru, altitude about 2,800 meters, June 16 to 24, 1923, by J. F. Macbride (no. 4870). Duplicate in U. S. National Herbarium.

This species belongs to the small group of *Bomarea* with relatively inconspicuous flowers in a compound umbel, of which *B. salsilla* L. is the best-known representative. *Bomarea nematocaulon* is a more slender plant than *B. salsilla*, the leaves are much thicker and have more numerous, more prominent, uniform nerves, and the petals are differently marked. The size and shape of the leaves and the small flowers suggest *B. sclerophylla*, a plant of the simple-rayed group of *Bomarea*, which, in addition, has glabrous leaves.

Bomarea angustissima Killip, sp. nov.

Caulis volubilis glaber; folia linearia caudato-acuminata subsessilia revoluta 7-9-nervia coriacea supra glabra subtus in nervis leviter pilosula; bracteae lineari-lanceolatae reflexae; umbella 3-radiata, radiis arcuato-adscendentibus

glabris 1-2-furcatis, bracteolis lineari-lanceolatis acutis; ovarium turbinatum glabrum; sepala oblanceolata obtusa; petala unguiculata sepala aequantia, medio abrupte dilatata, apice suborbiculata, viridia, intus purpureo-maculata.

Vine; stem subterete, tortuose, glabrous, light golden-brown; leaves linear, 8 to 10 cm. long, 3 to 5 mm. wide, caudate-acuminate and tortuose at apex, subsessile, strongly revolute, 7 or 9-nerved (nerves uniform), coriaceous, glabrous and dark green above, finely pilosulous on the nerves and glaucescent beneath; bracts linear-lanceolate, up to 1.5 cm. long and 2.5 mm. wide, reflexed; umbel 3-rayed, compound, the rays 12 to 15 cm. long, arcuate-ascending, purplish distally, glabrous, once or twice furcate, bracteolate at forks, the bracteoles linear-lanceolate, 0.5 to 1 cm. long, acute; ovary turbinate, glabrous, gradually tapering to base; sepals oblanceolate, 2 cm. long, 7 to 8 mm. wide, slightly cucullate, obtuse, proximally deep red, distally green; petals unguiculate, as long as the sepals, abruptly dilated at middle, the upper part suborbicular, about 1 cm. wide, green, purple-blotched within; stamens about as long as the perianth, the anthers oblong, 5 mm. long.

Type in the herbarium of the Field Museum of Natural History, no. 535,495, collected at Tambo de Vaca, Peru, altitude about 4,000 meters, June 10 to 24, 1923, by J. F. Macbride (no. 4409).

This is at once distinguished from all other Peruvian species of *Bomarea* by its very long, narrow leaves.

Bomarea speciosa Killip, sp. nov.

Caulis volubilis crassus glaber; folia late lanceolata cuspidata plana ca. 60-nervia membranacea glabra; bracteae lineari-lanceolatae mox deciduae; radii umbellae 10–12 crassi rufo-pilosuli viscidi 1 (raro 2)-furcati 1-bracteolati, bracteolis anguste oblongo-lanceolatis sessilibus; sepala oblanceolata subconcava ad apicem crassiora extus tenuiter puberula; petala sepalis subaequalia spathulata, extus alba et viridia puberula, intus alba, margine viridia, ubique purpureo-maculata et -punctata.

Vine; stem stout, tortuose, glabrous; leaves broadly lanceolate, 15 to 20 cm. long, 4.5 to 5 cm. wide, cuspidate-acuminate at apex, rounded at base, petiolate (petiole stout, about 1 cm. long), not revolute, about 60-nerved (nerves uniform), membranous, glabrous; bracts linear-lanceolate, about 2 cm. long, early deciduous; umbel compound, the primary rays 10 to 12, about 15 cm. long, stout, rufo-pilosulous, viscid, once or (rarely) twice furcate, bearing at the forks a narrowly oblong-lanceolate, sessile, rufo-puberulent bractlet up to 3 cm. long and 8 mm. wide, the secondary rays up to 6 cm. long; sepals oblanceolate, 4 to 5 cm. long, 8 to 10 mm. wide, slightly concave, apically thickened, pink, finely puberulent without; petals spatulate, subequal to the sepals, 12 to 15 mm. wide, the outside white proximally, green distally, the midnerve pink, puberulent, the inside white, green at margin, blotched and dotted with purple throughout; stamens and pistil subequal, slightly shorter than the sepals; anthers oblong, about 4 mm. long; style cleft about 1 cm.

Type in the herbarium of the Field Museum of Natural History, no. 534,773, collected in the montaña, Yanano, Department of Huánuco, Peru, altitude 1,800 meters, May 13 to 16, 1923, by J. F. Macbride (no. 3711). Duplicate in U. S. National Herbarium.

This belongs to the group of *Bomarea* species having a compound inflorescence and the perianth segments subequal. The very large flowers indicate an alliance with *B. hookeriana*, a plant with leaves densely strigillose beneath, and with much shorter, more numerous umbel rays. This may be *B. macrocarpa*, which I know only from Ruiz and Pavon's description and figure, and which has usually been considered a form of *B. ovata*. There are, however, many points of difference between the Macbride specimen and the diagnosis of *B. macrocarpa*.

Bomarea dolichocarpa Killip, sp. nov.

Caulis volubilis glaberrimus; folia lanceolata vel ovato-lanceolata, 25-30-nervia, nervis alternis prominentibus, membranacea utrinque glabra vel subtus in nervis tenuiter pilosa; radii primarii umbellae 3–6, 3–4-furcati bracteolati, bracteolis lineari-lanceolatis; ovarium anguste obprismaticum plus quam duplo longius quam latum, basi attenuatum glabrum vel leviter rufo-puberulum; sepala oblonga obtusa; petala spathulato-unguiculata sepalis aequalia vel parum breviora, ad basin rosea, ad apicem viridia purpureo-maculata.

Vine, with an elongate glabrous stem; petioles up to 1 cm. long; leaves lanceolate or ovate-lanceolate, 10 to 15 cm. long, 1.5 to 3.5 cm. wide, acute at apex, subcuneate at base, 25 to 30-nerved (alternate nerves prominent), membranous, glabrous throughout or finely pilose on the nerves beneath; bracts similar to the leaves, smaller; umbel compound, the rays up to 25 cm. long, glabrous or finely pilosulous, the primary rays 3 to 6, 3 or 4 times forked, bracteolate at forks with a linear-lanceolate bractlet up to 2 cm. long at the lowest fork, the upper bracteoles much smaller; ovary narrowly obprismatic, more than twice as long as broad, attenuate at base, glabrous or finely rufo-puberulent; sepals oblong, 2 to 3 cm. long, 6 to 9 mm. wide, obtuse, pink proximally, green distally; petals spatulate-unguiculate, as long as or slightly shorter than the sepals, 6 to 7 mm. wide, pink proximally, green and densely purple-spotted distally; stamens 1.5 to 2 cm. long, the anthers ovate, 2.5 to 3 mm. long; fruit narrowly obprismatic, 3.5 to 4 cm. long, 1.3 to 1.5 cm. wide, attenuate at base, apparently 1-celled.

Type in the U. S. National Herbarium, no. 1,460,267, collected at Puerto Yessup, Department of Junín, Peru, altitude 400 meters, July 10, 1929, by E. P. Killip and A. C. Smith (no. 26306). Duplicates at New York Botanical Garden and Field Museum.

Additional specimens examined.—

PERU: San Martín: San Roque, 1,350 to 1,500 meters, *L. Williams* 7022, 7326, 7771, 7679. Loreto: Puerto Arturo, near Yurimaguas, *L. Williams* 5290.

All these specimens have an elongate slender ovary, which becomes an elongate fruit nearly 4 cm. long, noticeably tapering to the pedicel. Because of its compound inflorescence, with the perianth segments subequal, the species obviously is related to *B. ovata*, a fact borne out by the coloring of the flowers. *Bomarea ovata* is the earliest described of the species of *Alstroemeria* now referred to *Bomarea*. It shows a good deal of variation and the list of names synonymous with *B. ovata* is a long one. Possibly one of these names applies to the species here proposed, but I have seen type material or illustra-

tions of most of these earlier species and none of them show the characteristic ovary of *B. dolichocarpa*.

BOTANY.—*A new species of* Hymenophyllum *from Peru.*[1] C. V. MORTON, U. S. National Museum. (Communicated by WILLIAM R. MAXON).

Mr. C. Bües, of Quillabamba, Peru, has collected many very interesting Peruvian ferns. A considerable number of these have been received by the U. S. National Museum through the kindness of Professor Fortunato L. Herrera, of the University of Cuzco. Included in the collection is a remarkable species of *Hymenophyllum*, here described as new.

Hymenophyllum amabile Morton, sp. nov.
Fig. 1

Euhymenophyllym; rhizoma longe repens parce ramosum fuscum 0.5 mm. diametro, pilis furcatis flavidis flaccidis pluricellularibus instructum, radicibus numerosis; stipites 2.5–6 cm. longi, 0.5 mm. diametro, teretes nec alati nigri nitidi dense pubescentes, pilis fuscescentibus stellatis stipitatis, demum glabrata; rhachis recta, teres, haud alata, 0.5 mm. diametro, pilis densissimis eis stipitis similibus; laminae pendulae lineares, 21–35 cm. longae, 3–4 cm. latae, pinnatae, pinnis pinnatipartitis; pinnae ovatae vel oblongae, maximae 2.5 cm. longae et 1.5 cm. latae, apicem versus gradatim reductae, sessiles, paullo decurrentes, haud surcurrentes, margine venisque densissime griseo-ferrugineo-pubescentes, pilis stipitatis ramis numerosis stellatis, rhachibus venisque vix flexuosis nigris; lamellae desunt; segmenta inferiora pinnatipartita, superiora semel furcata vel integra; segmenta ultima oblonga, maxima 4 mm. longa, omnia ca. 1 mm. lata, obtusa nec emarginata, nervis apicem non attingentibus, simplicia vel semel furcata; sori in lobulis extremis haud abbreviatis terminales; indusium non immersum, ad basin bilobum, lobis transverse ovalibus, ca. 0.6 mm. altum, 1 mm. latum, tenuissime membranaceum, fragile, margine integrum, extus densissime pubescens et ciliatum, pilis stellatis; sporangia numerosa in apicibus capitatis receptaculorum.

Type in the U. S. National Herbarium, no. 1,515,445, collected at Michihuañuncca, Huadquiña, Prov. de la Convención, Dept. Cuzco, Peru, alt. 3,000 meters, December, 1920, by C. Bües (no. 715).

Hymenophyllum amabile belongs to the *H. sericeum* group of species. It is distinguished at once from that species and its relatives *H. tomentosum*, *H. pyramidatum*, *H. lobato-alatum*, *H. fusugasugense*, and *H. plumosum* by the absence of wings on the secondary rhachises and veins. The remaining species of the group are *H. pulchellum*, *H. karstenianum*, *H. chrysothrix*, *H. spectabile*, *H. refrondescens*, *H. speciosum*, *H. buchtienii*, *H. elegantulum*, *H. sprucei*, *H. trichophyllum*, and *H. interruptum*. The last four named are

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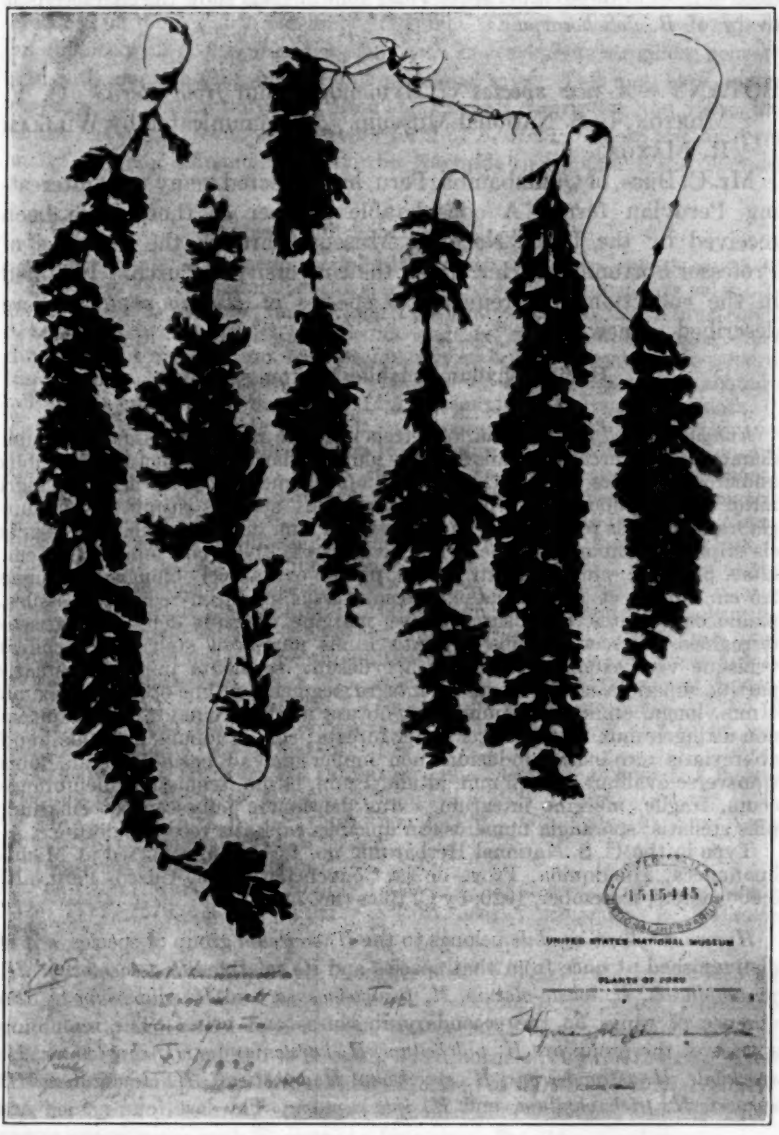

Fig. 1. *Hymenophyllum amabile* Morton, type specimen. Slightly less than one half natural size.

quite unrelated to the present species. The close, fine pubescence of *H. karstenianum*, *H. spectabile*, and *H. speciosum*, in which the individual hairs are not apparent except under magnification, is very different from the coarse pubescence of *H. amabile*, in which the individual hairs are prominent. All three of these species differ from ours also in their elongate, acuminate (rather than ovate or oblong, obtuse) pinnae. *H. buchtienii* Rosenst. and *H. pulchellum* C. & S. have pubsecence somewhat similar to the present species, but the hairs are less coarse and are sessile or only short-stipitate, in contrast to those of *H. amabile* which are long-stipitate. *H. buchtienii* (from Bolivia) is moreover a much smaller and more delicate plant with non-decurrent pinnae. *H. pulchellum* has a very different range (Mexico) and differs in several particulars from the present species, especially in its smaller size and less divided, petiolate (rather than sessile) pinnae. *H. refrondescens* Sod., of Ecuador, differs conspicuously in its alate rhachises and adnate pinnae; it is known to me from description only. *H. amabile* has terete non-alate rhachises and nearly free pinnae, i.e. not at all surcurrent and only slightly decurrent. *Hymenophyllum chrysothrix* Sturm, a little known species of Venezuela and Brazil, is perhaps most closely related, differing in its finer, less dense pubescence, broadly lanceolate (rather than linear) blade, petiolate (not at all decurrent) pinnae, and subimmersed indusia. The indusium of *H. amabile* is not at all immersed in the leaf tissue.

ZOOLOGY.—*Spawning reactions of three species of oysters.*[1] PAUL S. GALTSOFF, U. S. Bureau of Fisheries.

Since 1927 the author has been engaged in a study of the factors that control the shedding of eggs and sperm of the eastern oyster, *Ostrea virginica*. In 1929 the opportunity presented itself to experiment with the Japanese oyster, *O. gigas*, grown in Puget Sound, and during the summer of 1930 several experiments were carried out with the Australian oyster, *O. cucullata*, and *O. virginica* grown in the waters near Honolulu, T. H. A complete report of these investigations comprising nearly four hundred experiments will be published in the Bulletin of the Bureau of Fisheries.

The technique employed in all the experiments consisted in placing the oyster in a tank of about 20 or 30 liter capacity, in which the water was aerated, stirred and kept at constant temperature. In the majority of the experiments the thermo-regulators were set at 22.5°C. and they maintained this temperature within 0.5°C. The oyster was immobilized with plaster of Paris and one of its valves was attached to a light kymograph lever made of a strip of celluloid. It has been shown

[1] Published by permission of the U. S. Commissioner of Fisheries. Received January 5, 1932.

in a previous paper[2] that spawning of the female oyster consists of a series of the following reactions: contractions of the mantle, rhythmical contractions of the adductor muscle, and discharge of eggs. Rhythmical contractions of the muscle enable one to obtain a permanent record which can be easily analyzed. The results of a large number of experiments with *O. virginica* carried in 1927–1929 show that no spawning occurs below 20.0°C., whereas the same specimen reacts to the same suspension of sperm as soon as the temperature has been brought above 20.0°. In a few instances it has been noticed that oysters spawned at 27.5° without being stimulated by sperm. Inasmuch as in those cases unfiltered water was used the possibility of its contamination with sperm was not excluded. In the experiments with *O. gigas* it has been found that a ripe female oyster can be induced to spawn by a temperature of 30.0°C. The question naturally arises whether the same results could not be obtained with the other species. During the summer of 1931 experiments were carried out at Woods Hole with ripe oysters which were kept in aquaria at a temperature of about 20.0°C. To avoid possible contamination the water used in the experiments was filtered through a layer of asbestos about three quarters of an inch thick. The results of the experiments, summarized in Table 1, indicate without any doubt that ripe females can be induced to spawn by placing them in water having a temperature from 24.5° to 30.0°C. At 31.0°C. the females usually close their valves and remain closed until the temperature drops to 30° or 29°.

The latent periods of spawning reactions, i.e. the time elapsed from the moment the oyster was exposed to a given temperature until the beginning of spawning, varies from 22 to 257 minutes and apparently is not correlated with the temperature, the quickness of the response probably depending on the conditions of the organism itself. In a series of other experiments which can not be described in a brief article, the females which failed to respond to high temperature (26°–30°C.) readily responded to the addition of sperm. In all the experiments recorded in Table 1 the eggs discharged by the oysters were unfertilized and did not develop. The fact that the females can be stimulated by a temperature of 24.5° or higher suggested the possibility that a similar effect might be obtained by a longer exposure to temperatures between 20.0° and 24.5°C. The results of a long number of experiments, of which only three will be here described,

[2] Proc. Nat. Acad. Sci. **16**: 555–559. 1930.

show that this is very doubtful. On July 10 three ripe females were taken from the tank, in which the temperature during the previous week fluctuated between 18.5° and 19.5°C., and placed in an aquarium filled with filtered sea water. The temperature was kept at 22.6°C. but occasionally rose to 23.4°C. The shell movement of each oyster was recorded on the kymograph. The first oyster was kept for 5 hours 22 minutes, the second for 29 hours 53 minutes, and the third one for 73 hours 13 minutes. The water in the tanks in which the second and third oysters were kept was changed twice a day. None of the oysters spawned during that time but each of them spawned after sperm was added to the water the latent periods being 16, 24 and 15 minutes respectively.

TABLE 1.—SPAWNING REACTIONS OF THE FEMALES OF O. VIRGINICA INDUCED BY TEMPERATURE

Date in 1931	Experiment No.	Temperature °C.		Latent period in minutes	Duration of spawning in minutes
		Before experiment	During experiment		
July 10	325	19.5	24.5	65	43
9	321	19.9	25.0	22	118
7	317	19.9	25.3	250	46
9	322	19.9	26.0	257	38
8	318	19.9	28.0	32	25
8	319	19.9	28.5	55	44
17	340	20.4	30.0	20	?
8	320	19.9	30.0	42	52

It is interesting to note that in both cases of stimulation either by the temperature or by the sperm the reaction is alike and is characterized by a series of rhythmical contractions of the adductor muscle and of the mantle. From that an inference can be made that both factors release some mechanism in the organism of the female which in turn stimulates the adductor muscle and causes the discharge of eggs from the ovary. In this respect the reaction is not specific. It is, however, specific in the sense that sperm of other mollusks (*Mya* spp., *Mytilus* spp.) fail to induce spawning of the oyster. No positive results were obtained also when the sperm of *O. cucullata* was added to the female of *O. virginica* and vice versa. The last experiments are not conclusive, however, because of the failure of the specimens used in the experiments to spawn immediately upon the addition of the sperm of the same species. A few days later the shedding of eggs was successfully

stimulated by adding sperm of the same species. Attempts to fertilize eggs of *O. cucullata* by sperm of *O. virginica* and *vice versa* were unsuccessful. There was no formation of the fertilization membrane and no cleavage, whereas in the controls the eggs developed fairly well.

The spawning reaction of the male consists in a discharge of sperm which is carried away by the stream of water produced by the gill epithelium. The reaction is much simpler than it is in the female; it does not involve the adductor muscle and therefore can not be recorded on a kymograph. The males respond to the increase in temperature more readily than the females and often spawn in the tanks when the temperature reaches 24°C. Similar to the spawning of the females the shedding of sperm can be easily provoked by the addition of a few drops of egg suspension or egg water. Unlike the female in which the latent period lasts for several minutes the latent period of the spawning reaction of the male is of brief duration. It lasts only a few seconds. The reaction can be repeated many times until the male is spent. In case of *O. gigas* the males respond to egg suspension even when the water has been cooled to 12.5°C.

In 1930 several experiments with the two species of oysters, *O. virginica* and *O. cucullata*, were performed at Honolulu. The males failed to respond to the addition of sperm of another species but immediately reacted by discharging sperm to the addition of eggs of the same species. These results indicate very clearly the specificity of the response of the male to the presence of eggs. It would be very interesting to extend these experiments to other species of oysters the taxonomic characters of which, as for example those of *O. virginica* and *O. angulata*, are rather indistinct. There is no doubt that physiological differences that might be found would help in determining the validity of the present definitions of various species of the genus *Ostrea*.

Besides being stimulated by the temperature and egg suspension the males of *O. virginica* can be stimulated also by sperm. In that case the latent period of the reaction is approximately of the same duration as it is in the case of the stimulation of the female. A probable explanation is that the active principle of sperm suspension, being insoluble in the sea water, acts upon the organism through the digestive tract.

From a biological point of view stimulation of spawning either by the temperature or by the sperm and egg suspension is of great interest. It provides a mechanism which insures successful propagation of the

species. Should the temperature of the water fail to reach the effective point which would induce shedding of eggs by the females, still the spawning of the latter could be provoked by the sperm discharged by the males which are more susceptible to the increase in temperature. In most of the cases observed by the author when several oysters were kept together, the males spawned first and induced the shedding of eggs by the females. The process, once started, spreads by mutual stimulation of the two sexes throughout the whole oyster bed and results in simultaneous spawning of the oyster population.

MALACOLOGY.—*A new land shell of the genus* Rhiostoma *from Siam.*[1]

PAUL BARTSCH, U. S. National Museum.

Dr. Hugh M. Smith, Fisheries Adviser to His Majesty's Government, Bangkok, Siam, has sent to me for determination a magnificent specimen of *Rhiostoma*, which he collected at Kao Sabap, southeastern Siam, June 28, 1931, at an elevation of 450 meters.

Rhiostomas are ground-dwelling mollusks that frequent leaf mulch, burying themselves beneath such debris, and coming to the surface on moist days. Among a dozen or more known species of *Rhiostoma*, the present one has only one rival for size, namely, *Rhiostoma hainesi* Pfeiffer, from which it is at once distinguished by its lesser number of whorls, *Rhiostoma smithi* having but 5, while *Rhiostoma hainesi* has 7.

Rhiostoma smithi, n. sp.

Fig. 1

The shell is depressed helicoid, excepting the last two-fifths of the last turn which are solute, and which are deflected outward and downward. The under surface is openly umbilicated, all the whorls showing within the umbilicus. The early turns are straw-colored, the later whorls tending to pale olivaceous brown. In the type there are no color markings beyond this except an occasional darker varicial streak. (On the two paratypes, however, we have a subperipheral zone of chestnut brown and fine narrow axial vermiculations of brown. These, however, are not very conspicuous.) The early whorls are sufficiently eroded on the upper surface to make it impossible to differentiate the termination of the nuclear portion in the three specimens before us. The sculpture begins to show on the last half of the second whorl; from there on the shell is covered by a moderately thick periostracum. The sculpture of the shell consists of numerous, slender, threadlike wrinkles which assume almost the strength of slender lamellae on the summit of the whorls near the suture where they have been protected. This in reality represents projecting portions of the periostracum. These incremental threads are closely approximated and are of somewhat varying strength. They give to

[1] Published by permission of the Secretary of the Smithsonian Institution. Received December 18, 1931.

the surface of the shell a decidedly wrinkled appearance. What is said of the sculpture on the dorsal surface also obtains on the under side of the shell, the lines of growth extending into the umbilicus. The solute portion of the last whorl shows a feeble carina, corresponding to the posterior angle of the aperture, which is rendered conspicuous by the fact that the periostracum here is worn and leaves a white streak. This carina terminates anteriorly in the ear of the peristome The aperture is circular; the peristome is double, forming an ear or anteriorly open tube at the posterior angle of the aperture. This ear is rather short. The outer peristome is conspicuously expanded from the ear to the middle of the basal lip, becoming decidedly narrow on the parietal wall. The inner peristome projects slightly above the outer and is very slightly reflected. Both of them contribute to the production of the ear. The operculum forms a multispiral elevated cone, which is slightly concave in the middle on the outside. There are more than 14 whorls to the operculum. The outer portion of the operculum consists of an oblique calcareous lamina, which is spirally disposed and which bears on its outer surface a brownish periostracum which extends for a distance equaling the width of the lamella, beyond this being cut up into ragged fringes. The inside of the operculum is deeply cupped.

Fig. 1. *Rhiostoma smithi*

The type, U. S. N. M. No. 382943, has 5 whorls, and measures: Altitude, 20.3 mm.; greater diameter, 34.5 mm.; lesser diameter, 21.0 mm.

Two paratypes, U. S. N. M. No. 382944, have each 5 whorls, and measure: Altitude, 21 mm., 19.8 mm.; greater diameter, 34 mm., 32.3 mm.; lesser diameter, 22.3 mm., 20.2 mm., respectively.

PROCEEDINGS OF THE ACADEMY AND AFFILIATED SOCIETIES

THE ACADEMY

243D MEETING

The 243d meeting of the ACADEMY was a joint meeting with the Washington Society of Engineers and the District of Columbia Section of the American Society of Civil Engineers, and was held in the Auditorium of the Interior Department Building, on Thursday, November 19, 1931. About 200 persons were present. President COBB called the meeting to order at 8:20 P.M., and turned the chair over to Dr. R. S. PATTON, Director of the Coast and Geodetic Survey who introduced as speaker of the evening, Professor JYOJI SUYEHIRO, Director of the Earthquake Research Institute of The Tokyo Imperial University, who delivered an illustrated address, an abstract of which follows:

Program: J. SUYEHIRO: *Engineering aspects of earthquake research in Japan.* Two subjects were covered in this lecture—the Idu earthquake of November 26, 1929, and the effect of vibrations on buildings. The earthquake menace is accentuated in Japan because of the dense population but in fact very strong shocks occur only about once in 30 years. The numerous fore and after-shocks are often strong enough, however, to cause damage. As a result of the very great importance of these shocks to the people of Japan the interest of the Earthquake Research Institute, which was founded after the destructive shock of 1923, has been primarily directed towards local shocks rather than teleseismic shocks.

While the 1929 shock was in no way comparable with the great disaster of 1923, 261 persons lost their lives and 2,000 houses were destroyed. The shock is believed to have originated in the 30 km. long Tanna fault running north and south near the middle of the peninsula. A northward displacement of three feet is found on the east side of the fault. A large tunnel which crosses the fault was under construction at the time. No very serious damage occurred though the minor fault lines crossed the tunnel in about six different places. The ground through which the tunnel runs is mostly volcanic ash with some rock intrusion. Special instruments were installed to measure the minute slipping which continued after the main shock.

Fore shocks began 19 days in advance. Seven hundred and eighty-nine shocks were recorded in one day and 4,000 over a period of 56 days. Tilt measurements in this case showed nothing which could have been considered as predicting an earthquake. This may be related to the fact that the motion was chiefly horizontal. It happened that a line of levels was being run on the day before the earthquake in one direction and was repeated on the day afterwards but showed no difference. The change across the main fault was 20 cm. Triangulation results are not yet available. Seismographs in the tunnel and outside, constructed of stainless steel on account of the moisture, gave similar records except that small short-period vibrations on the outside instruments did not show up on the underground records.

For the purpose of studying the effects of earthquakes on buildings the latter are divided into three classes—strong, fairly strong, and weak. In the case of strong buildings the record made at the top of the building agreed very closely with that of the ground. In fairly strong buildings the similarity was not so marked while in weak buildings the record at the top showed almost entirely the natural period of the building and not the earthquake effect.

The inference to be drawn is that in designing buildings both forced and free vibrations must be considered. The view was expressed that the fate of a building is decided in the first 10 seconds of the shock. It is also felt in Japan that accelerations corresponding to periods of less than 1/3 second need not be considered in the study of strong earthquake motions as they are considered to be within the elastic limits of most structures. The opinion was further expressed that, while there is no real basis for adopting the maximum acceleration at any given percentage of g, such a practice with a properly adopted factor of safety is about the best that can be done until our knowledge becomes more complete.

CHARLES THOM, *Recording Secretary.*

SCIENTIFIC NOTES AND NEWS

ANDREW THOMSON, previously aerologist for the Meteorological Service of New Zealand and for some years director of the Apia Observatory, has been appointed meteorologist in the Canadian Meteorological Service.

DR. FREDERICK V. COVILLE, Curator of the Division of Plants of the National Museum, was recently awarded the George Robert White Gold Medal of Honor by the Massachusetts Horticultural Society for distinction in botanical fields.

At the thirty-ninth annual meeting of the Geological Society of Washington, held December 9, 1931, the following officers were elected: *President*, F. E. MATTHES; *Vice-Presidents*, F. L. HESS and H. G. FERGUSON; *Secretaries*, J. F. SCHAIRER and W. H. BRADLEY; *Treasurer*, C. WYTHE COOKE; *Members-at-large of the Council*, E. P. HENDERSON, T. B. NOLAN, FRANK REEVES, C. E. RESSER, and F. G. WELLS.

The Pick and Hammer Club met at the Geological Survey January 15. H. D. MISER discussed the conduct of the fifth annual field conference of the Kansas Geological Society; R. H. SARGENT described the work of topographers of the Geological Survey in Alaska and showed many colored slides; JOSIAH BIRDGE showed three reels of motion pictures of geologists at work in the southern Appalachians and other regions.

At a special meeting of the Pick and Hammer Club held at the Geological Survey, January 21, DR. F. A. VENING MEINESZ, professor of geodesy at the University of Utrecht, told of his work in a submarine on determinations of gravity at sea in the East and West Indies.

At the annual meeting of the American Anthropological Association held at Andover, Mass., December 28 and 29, 1931, Dr. JOHN R. SWANTON of the Bureau of American Ethnology was elected president for the ensuing year; DR. JOHN M. COOPER, Professor of Anthropology in the Catholic University of America, was reelected secretary, and Dr. FRANK H. H. ROBERTS of the Bureau of American Ethnology was made an associate editor of the *American Anthropologist*, the organ of the association.

The Cosmos Club on January 18 elected officers as follows: JOHN H. HANNA, *President;* ARTHUR L. DAY, *Vice-President;* D. L. HAZARD, *Secretary;* GEORGE E. FLEMING, *Treasurer;* HENRY GRATTAN DOYLE, HENRY C. FULLER, and NEIL M. JUDD, *Managers to serve until 1935;* JOHN H. MACCRACKEN, DELOS H. SMITH, and JOHN VAN RENSSELAER, *Members of the Committee on Admissions;* VICTOR S. CLARK, E. DANA DURAND, and J. WILMER LATIMER, *Members of the Endowment Fund Committee.*

H. W. KRIEGER, Curator of Ethnology, National Museum, left January 16 for the West Indies, where he will investigate shell heaps and other aboriginal remains on the islands of San Salvador and Cuba.